NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
4 Washington Place, New York 3, N. Y.

AMG-NYU No. 132
Copy No. 1 &

July 27, 1945

NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
4 Washington Place, New York 3, N. Y.

To: Dr. C. T. Elvey

From: Dr. J. K. L. MacDonald

Subject: Heat and gas flow in rockets.

This memorandum was written in response to your verbal suggestion that I indicate some types of devices and experiments which I think would be of value in the study of heat and gas flow in rockets. The following suggestions might be considered in connection with the program of research which was discussed on March 2 at Berkeley and was reported in the "minutes" and in the "outline" of past and future research (copies of which you have me recently).

The main points raised here are concerned with the experimental determination of values of physical parameters upon which reasonably accurate calculations relating to heat and gas flow in rockets can be based.

(A) Determination of physical properties of steel walls of rockets. As was stressed in the AMG-NYU Memorandum No. 104, p. 4, to make many reasonably accurate calculations on the behavior of steel walls of rockets under the influence of hot propellent gases it is necessary to have fairly accurate data on the temperature dependence of the thermal conductivity K, the heat capacity C and of the elastic moduli, as well as data on the quasi-latent-heats L of transformation of the actual steels used. The temperature range of interest is from 0°C to about 1000°C. It is suggested that calorimetric measurements should be made to determine K, C and L, using methods such as those described in the British "Second report of the alloy steels research committee", Iron and Steel Institute (London, 1939), (available, for example, on microfilm from the New York Public Library, 42nd Street, New York City). Before extending such measurements beyond 600°C, it might be advisable to check for temperature rate effects. Mr. H. Snyder, in particular, has expressed the opinion that for the high rates of heating that occur in rockets, "dynamic" behavior may make L effectively zero, and the transformations correspondingly incomplete. (But see the British reports [illegible]-2 (from 1943/29, AC.6020) and [illegible]-6 (from 1942/97, AC.5940) on temperature measurements and calculations for rockets.) Such behavior would require suitable modification of the numerical treatment. It therefore is suggested

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE
NAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING
E ESPIONAGE ACT, U.S.C. 50: 31 AND 32. ITS TRANS-
ON OR THE REVELATION OF ITS CONTENTS IN ANY MANNER
UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

NEW YORK UNIVERSITY, APPLIED MATHEMATICS

NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
25 Waverly Place, New York 3, N. Y.

that this matter be checked: (i) by a metallurgical examination of the type discussed at the Berkeley meeting, and (ii) by recording temperature-time histories at various rates of heating at various points in the steel, by means of an arrangement such as indicated in Fig. 1.



Fig. 1

M = rocket motor or case holding the grain.
G = powder grain.
S = steel tube under test (about 1/4" thick) with Θ_1, Θ_2, Θ_3 = three matched thermocouples in matched wells drilled as deep as possible in S (using small solid tubes of insulation around the thermocouple wire in each well and using external clamps if necessary for mechanical strength).
P = steel plug tapered to provide differing rates of heating at the thermocouples.
N = nozzles.

The arrangement somewhat resembles that used by Dr. Schmidt, but here the object is to obtain temperature records at various rates of heating. The thermocouple structures may be of the simple spark-welded type (suggested on p. 4 of the Berkeley March 2 minutes) and they should be rather closely matched in order to provide comparable oscillograms records (temperature vs. time). On the other hand accurate

RESTRICTED

absolute calibration of the thermocouples and estimation of heat deflection due to the wells is not necessary in these preliminary experiments. Dimensions of the components pictured in Fig. 1 should be chosen so that temperatures up to a out 900°C will be reached at various rates at the thermocouples. Probably several different sizes of G and P will be required to get a sufficiently wide range of rates of heating to be informative. The presence of a quasi-latent-heat of transformation will be indicated by a slight levelling off of the temperature-time curve near a critical temperature; otherwise rate effects may be noted (in which case the thermal research program for temperatures above 600°C will probably require the development of particularly accurate thermocouple structures).

(B) The design of non-perturbing thermocouple structures for the measurement of transient temperatures in walls of rockets has been discussed, in particular, in the AMG-NYU Memoranda Numbers 113 and 122, copies of which were sent to you. It is recommended that the design, precision construction and test of such structures be undertaken, keeping in mind points (on perturbation etc.) such as those raised in the above mentioned memoranda. Since any welding or metal foils may considerably alter the local thermal "constants" of the steel it would seem advisable to try to develop an ideal form of thermocouple as a standard for comparisons. It seems likely that the admittedly complicated constuction indicated in Fig. 2 would approach this ideal.



Fig. 2

(a) Cross section perpendicular to axis of rocket.

(b) Cross section parallel to axis of rocket.

RESTRICTED

RESTRICTED

R = steel wall of rocket (or removable plug made of the same steel as the wall).

W = wedge (about 1/4" long and of about 5° angle) made of fine porcelain (or other mechanically strong dielectric material with low heat capacity and low thermal conductivity). This wedge has a thin thermoelectric junction J formed (along the precision vertex line) by the meeting of thin layers of thermoelectrically stable metal pairs such as Pt and Pt 87% Rh 13 % sputtered or evaporated in vacuo onto respective faces of the wedge. The vertex line and junction should be "linear" within 10^{-5} inches to correspond to a 1°C accuracy in a typically maximum gradient of 10^{4} $^{\circ}$C per inch in the wall.

V = precision ground notch (about 8° angle) with line vertex matching that of W and running parallel to and at selected distance from the hot surface of R. The notch might be ground by use of a precision tapered rotary cutter making the side view of the notch as indicated in Fig. 2(b). Alternatively, for a steel plug R split along a plane through its axis, the precision grinding might be performed in the open on the two surfaces of the split, the plug then being carefully assembled (possibly in a steel bushing) and screwed into the wall of the rocket. Refinements would doubtless be suggested by tests.

In the above design the temperature in the steel would theoretically be hardly affected by the slot and wedge. Therefore, a high accuracy should be attainable provided that good thermal contact were obtained between the (deoxassed) apex of V and J, and provided that adequate electronic equipment were used (see AMG-NYU No. 113, p. 2 for amplifier reference). Such an "ideal" thermocouple could be used to test the accuracy of simpler designs with pressed gold foil or welded junctions such as those recommended in AMG-NYU No. 113 (paragraph 6) or such as those indicated in Fig. 3 below.



(a) Junction welded "in situ", possibly by use of spark.

(b) Assembled steel plug with welding of junction performed before insertion into wall.

(c) Simple plug construction for case of h" long enough for threading.

FIGURE 3.

RESTRICTED





RESTRICTED

NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
4 Washington Place, New York 3, N. Y.

R = wall of rocket
J = junction (two adjacent junctions at same distance h" from hot surface are required).
C = rod of metal forming one member of thermocouple
E = electrical lead
T (Fig. 3b) = very fine screw thread holding plug in wall

If a cylindrical rod is used for C it should satisfy the condition $Kd^4 \triangleq K'S'd^4$ (K and S being the thermal conductivity and the heat capacity of the steel, and K', S' of C. (See AMG-NYU No. 122, bottom of page 1.) The diameter d should not exceed the distance h". If $KS \triangleq K'S'$ then a slightly tapered form for C should be used (much as illustrated in Fig. 3c). To minimize perturbation in the reflected heat wave from the far end of C the length h' should be such that

$$\frac{h'}{K'} = \frac{h}{K} .$$

C. Gas flow in rockets. To provide some data for an accurate theoretical treatment of gas flow around a tubular powder grain it is suggested that small tungsten "flags" (vanes) be quite rigidly mounted at various points along the channels and that then one or more X-ray photographs be taken. The small vanes photographed edge on, should give an indication of the positions of stagnation points and of the degree of turbulence in the channels. For rather steady motion of the gas semi-quantitive measurements of velocities could possibly be obtained from X-ray pictures showing the deflection of a fine tungsten "pendulum" (with or without some elastic constraint). Such rather unorthodox methods seem to be necessary to study the rather extreme phenomena concerned.

If a transparent walled rocket could be fired successfully it would be of value to secure shadow and Schlieren movies (or stills) of the flow pattern.

Other Schlieren experiments on external blast fronts would be of interest theoretically, but discussion of them will be deferred until later.

RESTRICTED

NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
4 Washington Place, New York 3, N. Y.



KRAFT" FOLDER

Better folders for better files

K 9474 ⅔

Send your Order to the nearest "Y and E"
Representatives or to our Home Office

YAWMAN AND ERBE MFG. CO.

Main Factories and Executive Offices
ROCHESTER, N. Y.

Branches and Agents in all Principal Cities

NEW YORK UNIVERSITY
INSTITUTE OF MATHEMATICAL SCIENCES
LIBRARY
4 Washington Place, New York 3, N. Y.